THE LAKES OF TONGARIRO NATIONAL PARK

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ABSTRACT

Knowledge of physical, chemical and biological features of 12 mountain lakes (710-2774 m a.s.l.) within Tongariro National Park in the Taupo volcanic zone, central North Island, New Zealand is reviewed. Further information on 9 of the lakes is provided, based on a survey carried out in summer 1980-1981. The lakes are the thermal Ruapehu Crater Lake and the cold Rotopounamu, Tama Lakes, Blue Lake, Emerald Lakes and Lake Surprise. Five of the lakes are acidic (pH 1.2-5.2) with low levels of calcium, and in all except Rotopounamu a sparse flora and fauna occurs. Molluscs are absent from all lakes.

Rotopounamu, the best studied lake, has patchy beds of sedges on its southern shores, a low growing inshore community of submerged vegetation and a deeper characean algal community. No exotic aquatic plants were seen. Large populations of the galaxiid, *Galaxias brevipinnis* and the smelt, *Retropinna retropinna* are present.

KEYWORDS: Lakes, thermal, aquatic biology, water chemistry, fish, Tongariro National Park, North Island, New Zealand.

INTRODUCTION

Most of New Zealand's volcanic lakes lie within the Taupo volcanic zone which extends from the Tongariro volcanoes to White Island 250 km northeast in the Bay of Plenty. The lakes within Tongariro National Park are the southernmost of a series that also includes Taupo, Rotoaira and the Rotorua lakes.

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In this paper, knowledge of the physical, chemical and biological characteristics of 12 lakes is reviewed, and results of surveys made in 1980-81 are presented. Two unpublished reports (Michaelis, 1980, 1981b) provide more extensive descriptive accounts and data on the lakes and other freshwater habitats of Tongariro National Park.

THE LAKES

The location, altitude and catchment areas of the lakes surveyed are shown in Fig. 1 and Table 1. The map "Tongariro National Park" (New Zealand Mapping Series 273A) was used for site names, NZMS 1 maps for grid references and NZMS 2 sheets for greater detail. The lakes are the highest in the North Island and can be classified as montane, sub-alpine, alpine or nival. Crater Lake drains into the Whangaehu River system and Lake Surprise into the Wanganui River system but the others lie within the Tongariro River system. Morphometric characteristics of the lakes are summarised in Table 2. All are small and roughly circular with surface areas of less than 1 km^2 and low shoreline development. A small, unnamed lake recorded by Irwin (1975) 0.5 km northeast of Upper Tama Lake (NZMS1, N112/119777) was found to be only a clay pan and should be deleted from the list given by Michaelis (1980).

CRATER LAKE

Crater Lake on the summit of Mount Ruapehu is the best known lake in the National Park. Its thermal hydrology and chemistry have been discussed by Michaelis (1980) and Healy (1975) who noted that water temperature ranges from freezing point to 60°C depending on the level of volcanic activity. The lake has no visible inflows or permanent outlets and chemical analyses were necessary to show that the Whangaehu River is its outlet (Grange and Williamson, 1930; Fowles, 1981).

Volcanic activity of Ruapehu from 1861-1959 was reviewed by Gregg (1960). Major eruptions in December 1953 (which led to the Tangiwai railway disaster), June 1969 and April 1975 have been described, and their concomitant floods detailed by Odell (1955), Healy *et al.* (1978) and Nairn *et al.* (1979), respectively. The microbiology of three water samples from Crater Lake was studied by Brock & Brock (1971) and small numbers of tiny, curved, rod-shaped bacteria were found in one sample taken 6 months after an eruption.

ROTOPOUNAMU

Rotopounamu, the largest of the lakes, is on the flank of Mount Pihanga between Lakes Rotoaira and Taupo. A bathymetric map of

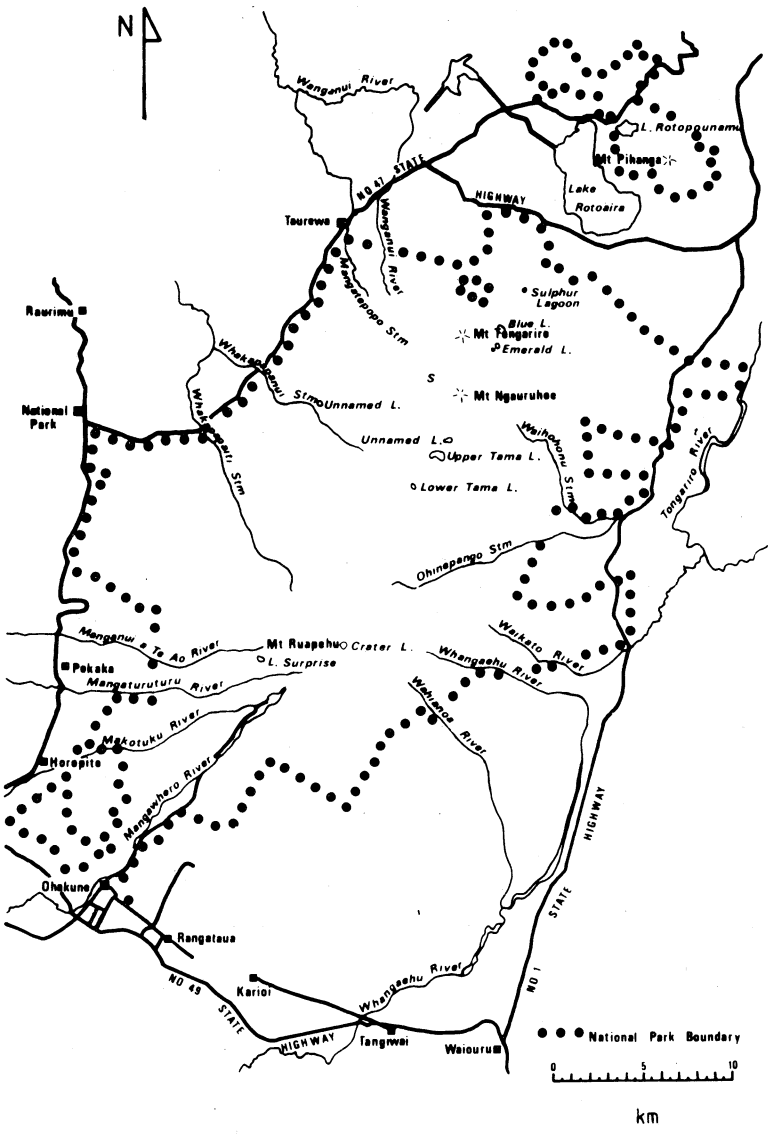

Fig. 1. Location of lakes in Tongariro National Park.

TABLE 1. LOCATIONS, ALTITUDES AND CATCHMENT AREA OF LAKES IN TONGARIRO NATIONAL PARK. (DASH DENOTES DATA NOT AVAILABLE).

	Crater[1]	Rotopoun-amu	Lower Tama	Upper Tama	Emerald[2] (3 lakes)	Blue	Sulphur Lagoon	Surprise[3]	Small, Unnamed[4] (2 lakes)
Location (NZMS 1)	N122/ 060657	N112/ 225965	N112/ 100752	N112/ 113772	N112/ 146834	N112/ 152847	N112/ 162872	N121/ 999644	N112/ 036803
Altitude (m)	2743	710	1250	1310	1650	1700	1300	1350	950
Catchment area (km^2)	1.16	5.54	1.49	1.57	0.12	0.60	0.36	-	0.38

[1] thermal [2] incorrectly recorded by Irwin (1975) [3] not recorded by Irwin (1975) [4] incorrectly recorded as 036003 by Irwin (1975)

TABLE 2. MORPHOMETRIC DATA FOR THE LAKES OF THE TONGARIRO NATIONAL PARK (e = estimated; dash denotes data not available)

	Crater	Rotopoun-amu	Lower Tama	Upper Tama	Emerald (1)	Emerald (2)	Emerald (3)	Blue	Surprise
Surface area A (km^2)	0.17	0.89	0.22	0.31	e0.012	e0.0026	e0.0016	0.16	0.011
Max length l (km)	0.56	1.31	0.58	0.79	e0.11	e0.06	e0.04	0.48	0.22
Mean breadth $b = A/l$ (km)	0.30	0.68	0.38	0.39	e0.11	e0.04	e0.04	0.33	0.05
Max depth (m)	0-300*	7.9	24.2	10.5	4.3	-	-	16.5*	0.8
Shoreline total length L (km)	-	3.80	1.74	2.55	-	-	-	1.45	0.60
Shoreline development $D_L = L/2\sqrt{\pi A}$	-	1.14	1.05	1.29	-	-	-	1.02	1.61

* Healy 1975.

Rotopounamu based on Irwin (1973) is given in Fig. 2. The lake has four small inflows but no visible outlet. Mean depth was calculated to be 4.65 m and volume 4.14 x 10^6 m^3. Rotopounamu was selected as a Project Aqua site for the International Biological Programme (Luther and Rzóska, 1971) but apart from the bathymetric map, no limnological data have been obtained and the aquatic flora is undescribed. Winterbourn (see Appendix I) recorded the presence of 23 animal species from the littoral zone and adjacent swampy pools in 1968-71, but noted an absence of molluscs. The lake has long been known to contain the native galaxiid *Galaxias brevipinnis* (koaro) (Phillips, 1924) and it was thought to be the only fish species present (McDowall *et al.*, 1975; McDowall, 1978).

UPPER AND LOWER TAMA LAKES (Ngapuna a Tama)

These two small lakes lie on the saddle between Ruapehu and Ngauruhoe in explosion craters (Thomas, 1889, Healy, 1975). None of the inflows are permanent. The lakes have no surface outlets but they probably feed springs that form the source of the Waihohonu Stream (Gregg, 1960).

EMERALD LAKES (Rotopounamu or Greenstone Lake)

Cussen (1891) recorded and Irwin (1975) listed two small lakes in large explosion craters, northeast of Red Crater on Ngauruhoe. Three lakes (or ponds) were found in this study (Fig. 3). Emerald Lake (1) overflows into the headwaters of the Oturere River.

BLUE LAKE (Te Wai-Whakaata-o-Te-Rangihiroa)

Blue Lake is a small circular lake in a crater on the summit of Tongariro (Bidwill, 1841, Gregg, 1960). It has no permanent inflows nor a visible outlet but may be a source of water for Ketetahi Hot Springs (Hector, 1867 in Beetham, 1880).

SULPHUR LAGOON

This temporary lake (length 250 m) lies in the lower Te Mari crater of Ngauruhoe (Cussen, 1891). A major eruption took place there in 1869 and the most recent eruption was in 1896. Present activity is restricted to small areas of fumaroles on the walls of the crater, which is usually dry but contains water after wet weather (Gregg, 1960). No data are available on the

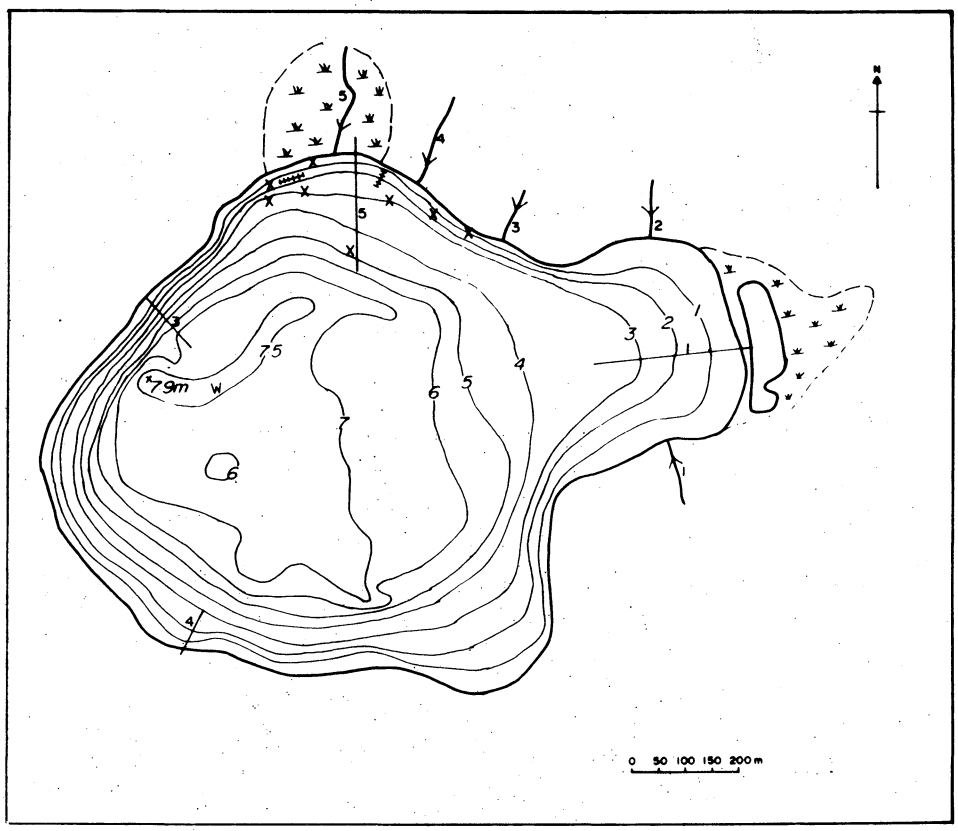

Fig. 2. Bathymetric map of Rotopounamu (after Irwin 1973) showing inflow streams, location of 4 transects, location of fish traps (X) location of gill nets, and water sampling sites (W).

temperature or chemistry of the lake water and the lagoon was not visited during the present study.

LAKE SURPRISE (Roto Ngaro)

This lake lies on a ridge between the Mangaturuturu and Manganui-a-te-Ao Rivers (Gregg, 1960). It has no permanent inflows but an apparent outflow occurs to the south after heavy rain.

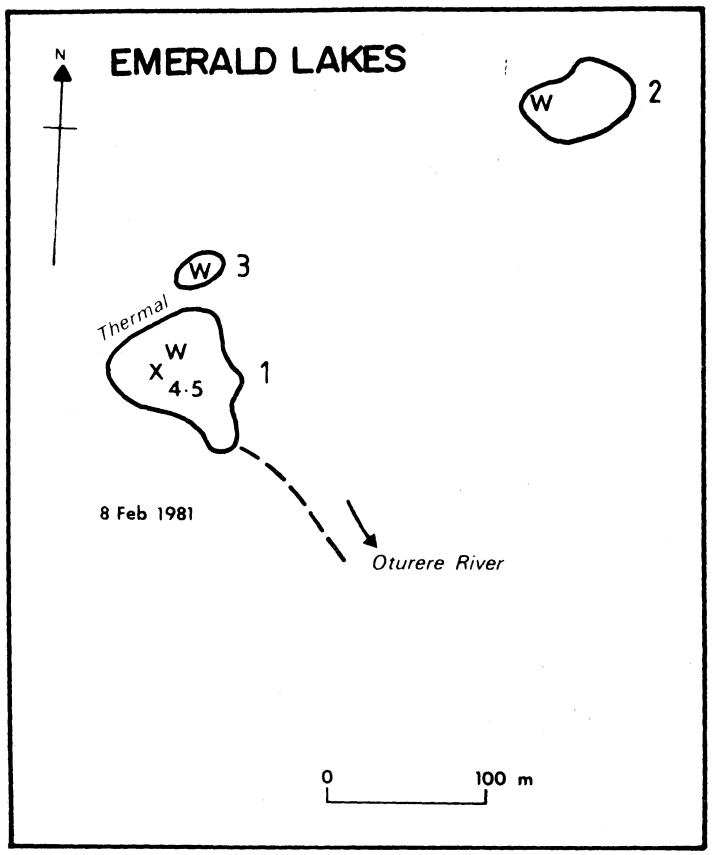

Fig. 3. Sketch map of Emerald Lakes 1, 2 and 3 showing location of sampling sites (W). Maximum recorded depth is indicated in metres.

LAKE SURVEYS, 1980-81

METHODS

Field parties visited Rotopounamu on 2 March 1980, 17-19 January 1981 and 25 January 1981, Tama Lakes on 6 February 1981, Blue Lake and Emerald Lakes on 8 February 1981, Lake Surprise on 14 March 1981, and Tama Lakes on 2 May 1981.

Duplicate water samples from each lake were collected in 500 ml plastic bottles and forwarded to Chemistry Division, D.S.I.R., Wairakei, and the Waikato Valley Authority for analysis. Secchi disc readings (water transparency) and plankton tows were made from an inflatable dinghy, and water temperature and dissolved

oxygen concentration were measured with a Yellow Springs Instruments probe and meter.

At Rotopounamu, semi-quantitative samples of bottom flora and fauna were collected at random along four representative transects (Fig. 2) by enclosing the substrate in a Wisconsin trap (0.09 m^2; 0.2 mm mesh). Because of the variety of substrate types, collections made at different sites were not always comparable. Algae were preserved in formalin: ethanol: water (1: 3: 6), whereas bryophytes were preserved in glycerol before drying (Michaelis, 1981a). Invertebrates were fixed initially in formalin and transferred to 70% ethanol following identification and counting. Attempts to collect fish were made with hand nets, a box trap, two collapsible Windermere traps, two gill nets (20 mm mesh) and a Fyke net. Nets and traps were set overnight on 17-18 January 1981 at sites shown in Fig. 2. Fish were placed immediately in formalin and taken to the laboratory where they were enumerated, measured and weighed. Aquatic macrophytes have been deposited with Botany Division, D.S.I.R., Christchurch and insects with the National Arthropod Collection, Entomology Division, D.S.I.R., Auckland.

PHYSICAL FEATURES

Temperature, dissolved oxygen and Secchi disc transparencies recorded during field surveys are summarised in Table 3. Rotopounamu was fully mixed (polymictic) in mid-summer with a surface temperature of 21.0°C and a bottom temperature of 18.0°C. This compares with previous summer records of 19.0-21.5°C at the surface on 24/25 February 1967 and 20.5°C at the surface and 19.8°C at the bottom in 1968 (Gordon, 1967; Larsen, 1968). Summer temperatures in the other lakes were constant at all depths (or to the limit of the temperature probe - 13.5 m) but lower than those in Rotopounamu. Upper Tama Lake was fully mixed in autumn when a temperature of 8°C was recorded.

The five lakes surveyed in summer contained 7.4 to 8.7 g $O_2.m^{-3}$ and Upper Tama Lake contained 9.7 g $O_2.m^{-3}$ in autumn (Table 3). Dissolved oxygen content varied little with depth as is usual for relatively unproductive lakes.

Secchi transparencies between 4.8 and 8.5 m recorded in the Tama Lakes and Blue Lake were relatively low for deep and unproductive Central North Island lakes (Green, 1975), however, the reading for Rotopounamu of 2.7 m is a typical value for a shallow lake. The comparatively low Secchi disc readings are probably not due to dense phytoplankton populations, but rather to the presence of fine detritus and silt (e.g. Rotopounamu) and also suspended and/or dissolved solids (e.g. Emerald Lakes). Seasonal variations in transparency can be marked so it is not known how typical the values were. Rotopounamu and the Blue Lake are not brilliantly coloured but the Emerald Lakes were a striking green. The reason for this is unclear.

TABLE 3. DEPTH OF SECCHI DISC VISIBILITY, WATER TEMPERATURE AND DISSOLVED OXYGEN CONCENTRATION IN THE LAKES OF TONGARIRO NATIONAL PARK. THE LOWER VALUE FOR TEMPERATURE OR DISSOLVED OXYGEN CORRESPONDS TO THE LAKE BOTTOM (OR LOWER LIMIT OF THE PROBE AT 13.5 m) AND THE HIGHER VALUE TO THE LAKE SURFACE.

	Rotopoun-amu	Lower Tama	Upper Tama	Emerald (1)	Blue	Surprise
Date	18 Jan 1981	6 Feb 1981	2 May 1981	8 Feb 1981	8 Feb 1981	14 Mar 1981
Secchi depth (m)	2.7	7.0	8.5	4.0	4.8	>0.8
Temp (^{o}C)	18.0 21.0	9.0 11.5	7.8 8.0	13.0 13.5	12.0	14.0
D.O. ($g.m^{-3}$)	7.4 7.6	5.6 7.2	9.7	8.4	8.6 8.7	7.9 8.1

CHEMICAL FEATURES

Chemical features of the nine lakes surveyed are shown in Table 4. Crater Lake is highly acidic and strongly mineralised (Giggenbach, 1974, Ellis and Mahon, 1977) and its waters can be classified as acid-sulphate-chloride (Ellis and Mahon, 1964). Using the terminology of McColl (1975), the three Emerald Lakes would be classed as acid-sulphate waters, the Tama Lakes as chloride-sulphate waters and the Blue Lake and Lake Surprise as bicarbonate waters. The two bicarbonate waters probably lack thermal inflows. McColl (1975) listed chemical features of 15 lakes north of Tongariro on the Volcanic Plateau and showed that they had an average ion equivalent composition biased towards monovalent ions and a Ca: Mg ratio of about 1 or less. In contrast, non-thermal lake waters in the Tongariro region were biased towards divalent ions and the Ca: Mg ratio varied between 1:1 and 43:1.

BIOLOGICAL FEATURES

ROTOPOUNAMU

Macrophytes

The macrophytes of Rotopounamu are listed in Table 5. All species recorded are indigenous and two distinct communities of attached plants could be recognised. One of these was a shallow,

TABLE 4. RESULTS OF CHEMICAL ANALYSES OF WATER SAMPLES FROM NINE LAKES IN TONGARIRO NATIONAL PARK. Concentrations are per m^3. ND = not detectable; - = not analysed; + = total hardness.

	Crater	Rotopounamu	Lower Tama	Upper Tama	Emerald (1)	Emerald (2)	Emerald (3)	Blue	Surprise
Date sample collected	6 Feb 1973	19 Jan 1981	6 Feb 1981	6 Feb 1981	8 Feb 1981	8 Feb 1981	8 Feb 1981	8 Feb 1981	14 Mar 1981
pH	1.18	7.1	7.45	6.04	3.2	4.55	3.14	5.2	6.17
Conductivity ($mS.m^{-1}$)	-	-	-	-	-	-	-	-	10 ⊕
HCO_3(g)	-	-	0.4	0.9	0	0	0	13.3	8.5
NO_3 - N (mg)	-	2.5	6.3*	8.9*	-	-	-	-	-
NH_4 - N (mg)	11800	-	432*	27*	-	-	-	-	-
Total P (mg)	-	6.0-27.6	29.5*	10.4*	-	-	-	-	-
Cl (g)	12650	-	3	2	2	2	3	2	2
SO_4 (g)	16800	-	2	2	61	32	118	1	2
Na (g)	1110	-	0.80	0.93	1.05	2.83	2.87	0.46	1.04
K (g)	202	-	0.1	0.1	0.2	0.4	0.3	0.1	0.1
Ca (g)	1540	>3	0.4	0.3	1.2	3.2	3.4	ND	9.4
Mg (g)	1590	>3	0.11	0.19	1.44	2.21	1.64	0.60	0.22
Fe (g)	400	-	ND	ND	0.24	ND	1.4	ND	ND
Cu (g)	200	-	ND	ND	ND	ND	0.08	ND	ND

Sources of data: Crater, Giggenbach (1974, sample 33); Rotopounamu, Waikato Valley Authority; Others, Chemistry Division, D.S.I.R., Wairakei except ⊕ Rangitikei - Wanganui Catchment Board, * Waikato Valley Authority.

TABLE 5. AQUATIC MACROPHYTES RECORDED FROM LAKE ROTOPOUNAMU DURING THE PRESENT STUDY.

ALGAE: CHARACEAE

Nitella pseudoflabellata (Nordst.) Bailey

Nitella leptostachys var *leonhardii* (R.D.W.) R.D.W.

BRYOPHYTA:

Telaranea tetradactyla (Hook.f.et Tayl.) Hodgs.

Symphyogyna undulata Col.

Symphyogyna prolifer Col.

DICOTYLEDONES

Myriophyllum pedunculatum Hook.f.

Myriophyllum propinquum A.Cunn.

Lilaeopsis lacustris Hill

Glossostigma elatinoides Benth.

Eleocharis sphacelata R.Br.

Eleocharis acuta R.Br.

Baumea rubiginosa (Spreng.) Boeck.

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inshore community consisting of a restricted number of low growing species comparable in structure to the "low growing community" of Chapman *et al.* (1971) (0.1-2.5 m deep). The second community comprised a rich meadow of two characean species extending from a depth of 2.5 m to the bottom of the lake (7.9 m).

Invertebrate fauna

Species recorded during the present study are listed in Table 6. Larval insects were most abundant in the littoral zone, and no molluscs were recorded. This confirms an earlier report by Winterbourn and Lewis (1975). Swampy habitat along the shoreline was not sampled during the present study but it is known to provide an important habitat for a diverse aquatic fauna (Appendix I).

Vertebrate fauna

Two species of fish and the tadpoles of the introduced frog *Litoria aurea* (Lesson) were observed in the lake. The koaro, *Galaxias brevipinnis* Günther, was observed during the daytime by a team of six experienced SCUBA divers working along four transects (Fig.2). As this fish is known to be secretive and a nocturnal forager (McDowall, 1980), a night dive was carried out by two

TABLE 6. AQUATIC INVERTEBRATES RECORDED FROM LAKE ROTOPOUNAMU DURING THE PRESENT STUDY.

Oligochaeta

Tubificidae indet.

Copepoda

Boeckella propinqua Sars
Cyclopoida indet.

Odonata

Xanthocnemis zealandica (McLachlan)
Hemicordulia australiae (Rambur)
Procordulia grayi (Selys)
Diplacodes bipunctata (Brauer)

Hemiptera

Microvelia sp.
Anisops assimilis White
Sigara arguta (White)
Diaprepocoris zealandiae Hale

Coleoptera

Liodessus plicatus (Sharp)
Homeodytes hookeri (White)
Helodidae (larvae) indet.

Diptera

Chironomus zealandicus Hudson
Macropelopiini indet.
Orthocladinae indet.

Trichoptera

Polyplectropus sp.
Triplectides cephalotes (Walker)

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divers on 18 January 1981 (2130-2230 h NZST). This showed that smaller koaro were numerous at depths less than 1 m and larger fish were present between 2 and 4 m (the latter being the maximum depth reached by divers). Altogether, 133 specimens were taken at night, 131 in gill nets and 2 in handnets. Most fish were caught within 0.5 m of the bottom of the gill net (lake depth 2.0-2.5 m) swimming from east to west (Fig.2). No fish were taken in the fish traps. The 133 fish captured ranged from 82 to 137 mm in length, with most between 80 and 111 mm. They probably represent the 1+ year class. The absence of smaller fish probably reflects the selectivity of the gill net. Six fish captured were between 120 and 137 mm in length and were probably in the 2+ year class. Further details are recorded by Michaelis (1981b).

The other fish recorded was the common smelt, *Retropinna retropinna* (Richardson), a species not previously known from

Rotopounamu (Richmond, 1974). No fish were seen swimming in the lake in daytime but two specimens were found dead on the shoreline. The remaining 14 specimens were taken in handnets at night. Underwater observations at night suggested that the species was common in mid-water. Fish ranged in length from 60 to 100 mm, and were somewhat larger than most *R. retropinna* which are restricted to inland freshwaters (McDowall, 1978). This suggests it may be a recent introduction to the lake.

TAMA LAKES

In Lower Tama Lake, algae were widespread on the sandy substrate in shallow water but no aquatic macrophytes were observed. However, in Upper Tama Lake, a liverwort *Eoisotachis stephanii* (Salm.) Schust, was abundant at a depth of about 5 m. It was previously known only from Stewart Island and Fiordland (E.O. Campbell, Massey University, pers. comm.). Around the edges of Lower Tama Lake, pupal cases of a caddisfly *Polyplectropus* sp. were common.

EMERALD LAKES

In all three Emerald Lakes, an alga, possibly *Zygogonium ericetorum* Kutz, covered the lakebottom. The shoreline consisted of stones coated in a fine, yellow-brown sediment amongst which no benthic invertebrates were seen.

BLUE LAKE

No benthic algae were observed on the sandy substrate of Blue Lake but pupal exuviae of a chironomid, *Gressittius antarcticus* (Hudson) were collected from the water surface. No other benthic invertebrates were recorded.

LAKE SURPRISE

The submerged macrophyte *Myriophyllum pedunculatum* Hook.f. was widespread on the silty substrate of this shallow lake. The benthos was dominated by oligochaete worms and larvae of the chironomid *Gressittius antarcticus*. Other insects abundant in the water included larvae of the red damselfly *Xanthocnemis zealandica* (McLachlan), helodid beetle larvae and the common backswimmer, *Anisops assimilis* White.

DISCUSSION

The high altitude, North Island volcanic lakes studied here differ both chemically and biologically from South Island lakes of glacial origin (see e.g. Stout, 1977). Lakes on the volcanic plateau are geologically young and may be affected by volcanic eruptions including ash showers which emanate from Ngauruhoe at irregular intervals. Some of the lakes are highly acidic. Both sub-alpine and alpine lakes had impoverished faunas and floras with low standing biomass and by inference, low productivity. This was probably due to a combination of low temperature, short growing season and low nutrient levels (Stout, 1977) and, in acid lakes, the absence of bicarbonate as a carbon source (Bayly and Williams, 1973). The relatively productive nature of the montane Lake Rotopounamu was in marked contrast to the higher altitude lakes studied. One of its most interesting features is the absence of introduced aquatic macrophytes, a characteristic it shares with only a few other lakes such as Waikareiti in Urewera National Park (P. Mylechreest, Wildlife Service, Department of Internal Affairs, pers. comm.), and Rotokawau and Rerewhakaaitu in the Rotorua area. The absence of molluscs from Rotopounamu is also notable since they are present in nearby Lakes Taupo and Rotoaira. Freshwater molluscs have yet to be recorded from Tongariro National Park, although the ubiquitous freshwater snail *Potamopyrgus antipodarum* (Gray) has been collected in the Mangatepopo Stream below the Park Boundary (Michaelis, 1980).

ACKNOWLEDGEMENTS

This study was financed by the National Parks and Reserves Authority and the Lottery Profits, Scientific Research Distribution Committee. Laboratory facilities were kindly provided at the Fisheries Research Division, Ministry of Agriculture and Fisheries, Rotorua, and chemical analyses were performed by Chemistry Division, D.S.I.R., Wairakei and the Waikato Valley Authority, Hamilton. I thank the Chief Ranger of Tongariro National Park, B.E. Jefferies, and all those who took part in field expeditions, especially my husband, G.C. Wells. Several people assisted with identifications: E.O. Campbell (liverworts); J.S.Clayton (characeans and submerged macrophytes); C.Ecroyd (sedges); G.S.Hardy (frogs) and W.J. Winstanley (eggs of Odonata).

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APPENDIX 1. Animal species collected by M.J. Winterbourn in littoral pools and swamp alongside Rotopounamu in August 1968 and January 1971 (P = present, - = not seen).

	August	January
Oligochaeta		
Tubificidae indet.	P	P
Copepoda		
Boeckella propingua	P	-
Cyclopoida indet.	P	-
Odonata		
Xanthocnemis zealandica	P	P
Austrolestes colensonis (White)	-	P
Hemicordulia australiae	-	P
Hemiptera		
Microvelia sp.	P	P
Anisops assimilis	P	P
Sigara arguta	P	P
Diaprepocoris zealandiae	P	P

Coleoptera		
Liodessus plicatus	P	-
Homeodytes hookeri	-	P
Helodidae indet.	P	P
Hydrophilidae indet.	-	P
Diptera		
Chironomus zealandicus	P	-
Macropelopiini indet.	-	P
Orthocladiinae indet.	-	P
Ceratopogonidae indet.	P	P
Trichoptera		
Polyplectropus sp.	P	P
Triplectides cephalotes	-	P
Hydracarina		
(?) *Arrenurus* sp.	P	P
Anura		
Litoria sp.	-	P